July 30, 1968 D. S. STEPHENS 3,395,373

THREE-PHASE TRANSFORMER HAVING FOUR CORE LEGS

Filed Aug. 31, 1966 2 Sheets-Sheet 1

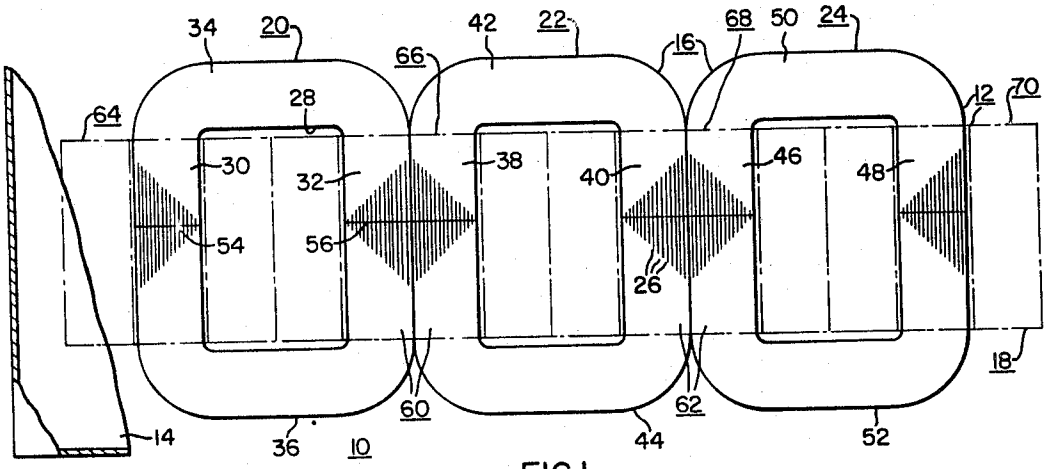

FIG.1.

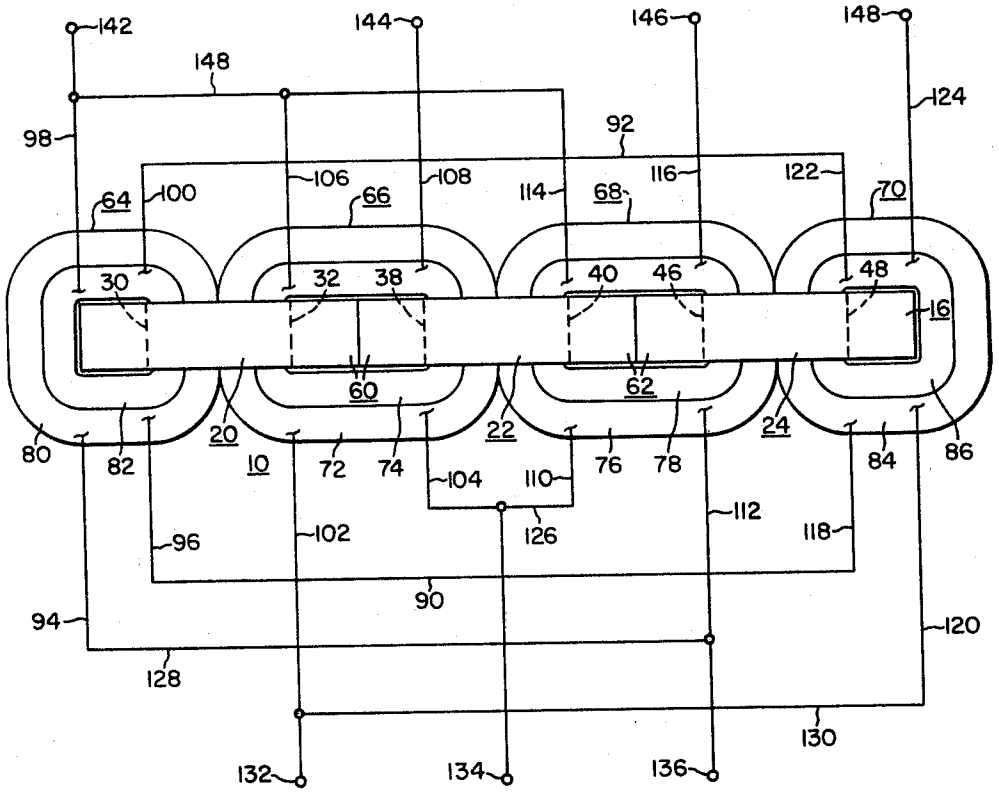

FIG.2.

WITNESSES

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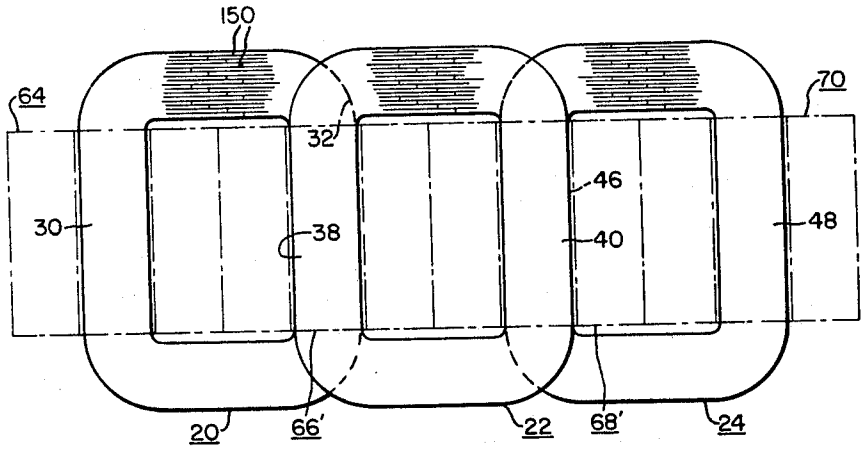
FIG. 3.



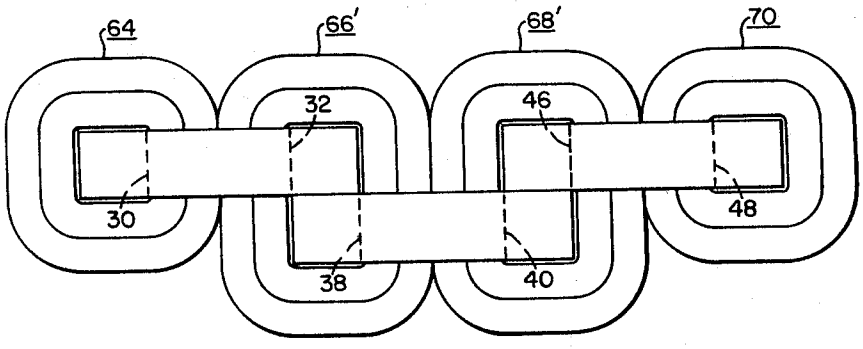


FIG. 4.

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THREE-PHASE TRANSFORMER HAVING FOUR CORE LEGS

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ABSTRACT OF THE DISCLOSURE

A three-phase transformer having first, second and third wound type magnetic core sections, each having two leg portions. The three magnetic core sections are disposed adjacent one another to provide first, second, third and fourth winding legs. The second and third winding legs include leg portions from the first and second magnetic core sections, and the second and third magnetic core sections, respectively. The first and fourth winding legs are single leg portions from the first and third magnetic core sections, respectively. First, second, third and fourth winding sections are disposed in inductive relation with the first, second, third and fourth winding legs, respectively, with the second and third winding sections each forming a phase of the three-phase transformer, and with the first and fourth winding sections being serially connected to provide the third phase.

This invention relates in general to electrical inductive apparatus, such as transformers, and more particularly to winding and magnetic core structures for polyphase electrical inductive apparatus.

Three-phase transformers having wound-type magnetic cores have been used for many years. One of the reasons they have not been completely replaced by stacked type polyphase magnetic cores, is the fact that the size of the wound-type polyphase cores may be easily and inexpensively changed, compared with the cost of new punching dies for obtaining new lamination sizes for polyphase stacked type cores.

The conventional three-phase wound-type magnetic core, however, has certain disadvantages. The fact that it has three single-phase type core sections does not facilitate the manufacture of the core. In fact, the necessary mechanical interdependence of the three single-phase type core sections greatly multiplies the manufacturing problems. For example, two similar single-phase type wound sections must first be wound upon separate mandrels. Then, these two magnetic core sections, along with their mandrels, are disposed on a face plate, and the third magnetic core section is wound about the first two magnetic core sections. This forms a very awkward structure, which must be removed from the winding machine and blocked to shape. Each of the magnetic core sections must then be cut to form two matching halves, in order to facilitate assembly with its associated electrical windings. The cut ends of the matching halves are ground and etched, and the sections are then reassembled and banded in conjunction with the electrical windings. The close tolerances between the various magnetic core sections, necessary in order to reduce core losses to a minimum, creates manufacturing problems related to maintaining dimensional accuracy. Also, the banding of the three-phase wound-type

core does not force the inner legs of the core tightly together; in fact, the banding tends to distort the core.

In addition to the hereinbefore mentioned mechanical and manufacturing problems, the resulting structure is not magnetically balanced, as the end or outer legs do not have equal reluctance through the other two legs.

Accordingly, it is an object of the invention to provide a new and improved three-phase transformer having a wound-type magnetic core.

A further object of the invention is to provide a new and improved three-phase transformer having a wound-type magnetic core structure formed of three similar single-phase type core sections each having substantially the same dimensions, and which are not mechanically interdependent.

Another object of the invention is to provide a new and improved three-phase transformer having a wound-type magnetic core structure which requires less magnetic material than similarly rated structures of the prior art.

Still another object of the invention is to provide a new and improved three-phase transformer having a wound-type magnetic core structure which has three similar single phase type core sections which may be separately banded.

Another object of the invention is to provide a new and improved three-phase transformer having a wound-type magnetic core structure which has a substantially balanced magnetic circuit.

Another object of the invention is to provide a new and improved three-phase transformer having a wound-type magnetic core structure which is easier to manufacture than certain wound-type polyphase magnetic core structures of the prior art.

Briefly, the present invention accomplishes the above cited objects by providing a three-phase transformer having a new and improved three-phase magnetic core and winding structure which requires the use of three single-phase type magnetic core sections. The three single-phase magnetic core sections have similar dimensions, and are disposed adjacent one another to form two winding legs which are made up of the legs of two adjacent core sections, and two winding legs each of which is a leg of a single core section, having one half the cross sectional area of one of the other legs. First, second, third and fourth winding structures or sections are provided, each having primary and secondary coils. The primary coils and the secondary coils of each of the winding structures have a like number of turns, respectively, with the second and third winding structures being dimensioned to encircle the winding legs formed by the two adjacent magnetic core sections, and the first and fourth winding structures being dimensioned to encircle the remaining winding legs, formed by the single magnetic core structures. The second and third winding structures form two of the three phases of the transformer. The primary coils and the secondary coils of the first and fourth winding structures are serially connected, respectively, to form the third phase of the transformer. Thus, three similarly dimensioned single-phase type cores, which have no critical interrelated dimensions, are utilized to provide a new and improved three-phase transformer structure which requires less magnetic core material than certain three-phase wound-type magnetic core structures of the prior art, and which has a substantially balanced magnetic circuit.

Further objects and advantages of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is an elevational view of a three-phase transformer having a wound-type magnetic core structure and associated windings constructed according to the teachings of the invention;

FIG. 2 is a plan view of the three-phase transformer structure shown in FIG. 1, which includes a schematic diagram illustrating how the windings may be connected;

FIG. 3 is an elevational view of a three-phase transformer constructed according to another embodiment of the invention; and

FIG. 4 is a plan view of the transformer construction shown in FIG. 3.

Referring now to the drawings, and FIG. 1 in particular, there is shown an elevational view, partially cut away, and partially in phantom, of a three-phase transformer **10** constructed according to the teachings of the invention. Transformer **10** includes a core-coil assembly **12**, disposed in a suitable casing or tank **14**, which is shown cut away in order to more clearly illustrate the core-coil assembly **12**. The core-coil assembly **12** includes a magnetic core structure **16**, and a winding structure **18**, which is shown in phantom in FIG. 1 to more clearly illustrate the magnetic core structure **16**.

Magnetic core structure **16** includes three single-phase type magnetic core sections **20**, **22**, and **24**, which have similar dimensions. Each of the magnetic core sections is of the wound type, being formed of a strip of metallic, magnetic material, such as singly or multiply oriented silicon steel, which is wound upon a mandrel to provide a predetermined number of nested or superposed lamination turns **26**. Each magnetic core section has an opening or winding window **28** for receiving its associated winding, a predetermined radial build made up of the plurality of nested lamination turns, a depth determined by the strip width, and the core sections are shaped to provide two winding legs, and two connecting yoke portions. For example, magnetic core section **20** has winding legs **30** and **32**, and yoke portions **34** and **36**; magnetic core section **22** has winding leg portions **38** and **40**; and yoke portions **42** and **44**; and, magnetic core section **24** has winding leg portions **46** and **48**, and yoke portions **50** and **52**.

Each of the magnetic core sections may have an openable joint, such as the butt-type joint **54** in leg **30**, and the butt-type joint **56** in leg **32**, of magnetic core section **20**, in order to facilitate the assembly of the winding structure **18** with the magnetic core sections. Thus, using butt-type joints **54** and **56**, each magnetic core section is divided into two type C cores, which are held together by suitable banding means (not shown).

The assembly of the magnetic core sections to form magnetic core assembly **16** requires only that the core sections **20**, **22** and **24** be disposed in side-by-side relation, with their leg portions adjacent to one another. For example, as shown in the embodiment illustrated in FIG. 1, the outer lamination turns of the various leg portions are disposed adjacent to and in substantially contacting relation with one another, forming a magnetic core assembly **16** in which the various magnetic core sections are disposed in a common plane. Thus, two inner and two outer winding legs are formed, with the end or outer winding legs being similar in cross section, and comprising leg portion **30** of magnetic core section **20** and leg portion **48** of magnetic core section **24**. The two inner winding leg portions are formed by the two adjacent leg portions of magnetic core sections **20** and **22**, and the two adjacent leg portions of magnetic core sections **22** and **24**, with leg portions **32** and **38** forming a single winding leg **60**, and leg portions **40** and **46** forming a single winding leg **62**. Winding legs **60** and **62** therefore, have twice the cross sectional area of winding legs **30** and **48**.

In describing the winding structure **18**, which is shown in phantom in FIGURE 1, FIG. 2 will also be referred to, which is a plan view of the transformer **10** shown in FIG. 1, and which illustrates the winding structure **18** in full. Winding structure **18** includes four winding sections **64**, **66**, **68** and **70**, disposed in inductive relation with winding legs **30**, **60**, **62** and **48**, respectively.

Winding section **66** includes primary and secondary coils **72** and **74**, respectively, as shown in FIG. 2, each having a predetermined number of conductor turns, which forms one of the phases of transformer **10**. In like manner, winding section **68** includes primary and secondary coils **76** and **78**, respectively, each having the same number of conductor turns as the primary and secondary coils, respectively, of winding section **66**, with winding section **68** forming another of the phases of transformer **10**. Since winding sections **66** and **68** have the same number of conductor turns and since they both encircle the winding leg having substantially the same cross sectional configuration and area, winding sections **66** and **68** are similar in size, weight and appearance.

The remaining phase of three-phase transformer **10** includes both winding sections **64** and **70**. Winding section **64** includes primary and secondary coils **80** and **82**, respectively, and winding section **70** includes primary and secondary coils **84** and **86**, respectively, as shown in FIG. 2. The primary coils **80** and **84** of winding sections **64** and **70** are serially connected, and the secondary coils **82** and **86** of winding sections **64** and **70** are serially connected, as will hereinafter be described.

Since winding sections **64** and **70** encircle winding legs **30** and **48**, respectively, which have one half the cross sectional area of winding legs **60** and **62**, the primary coils **80** and **84** each require the same number of conductor turns as each of the primary coils **72** and **76** of winding sections **66** and **68**, and the secondary coils **82** and **86** each require the same number of conductor turns as each of the secondary coils **74** and **78** of winding sections **66** and **68**. Winding sections **64** and **70**, each have the same number of conductor turns, and each encircle a winding leg of substantially same cross sectional configuration and area, and thus are similar in size, weight and appearance to one another.

Winding sections **64** and **70**, having the same number of conductor turns as winding sections **66** and **68**, will have the same radial build dimension, but will have a shorter mean turn length due to the smaller cross sectional area of their associated winding legs.

As shown in FIG. 2, each of the primary and secondary coils of each of the winding sections have two leads, which connect to opposite ends of the coils, respectively. Winding section **64** has leads **94** and **96** connected to primary coil **80** and leads **98** and **100** connected to secondary coil **82**; winding section **66** has leads **102** and **104** connected to primary coil **72**, and leads **106** and **108** connected to secondary coil **74**; winding section **68** has leads **110** and **112** connected to primary coil **76** and leads **114** and **116** connected to secondary coil **78**; and, winding section **70** has leads **118** and **120** connected to primary coil **84** and leads **122** and **124** connected to secondary coil **86**.

As hereinbefore stated, the primary coils **80** and **82** of winding sections **64** and **70** are serially connected, as shown by conductor **90**, and the secondary coils **82** and **86** of winding sections **64** and **70** are serially connected, as shown by conductor **92**, with the serially connected primary and secondary coils forming one of the winding phases of transformer **10**. The primary and secondary coils may be connected in any desired three-phase configuration. For purposes of example, primary coils **72**, **76** and the serially connected primary coils **80** and **84**, are shown connected in delta, with leads **104** and **110** being connected together via conductor **126**, leads **94** and **112** being connected together via conductor **128**, and leads **102** and **120** being connected together via conductor **130**. Conductors **130**, **126** and **128** are connected to line terminals **132**, **134** and **136**, respectively.

Also, for purposes of example, secondary coils **74** and **78**, and the serially connected secondary coils **82** and **86**, are shown connected in wye, with leads **98**, **106** and **114** being connected together via conductor **148**, and to neutral terminal **142**, and leads **108**, **116** and **124** being connected to terminals **144**, **146** and **148**, respectively.

Thus, the three-phase transformer construction shown in FIGS. 1 and 2 utilizes three single-phase type wound magnetic core sections, all having substantially the same dimensions, and mechanically related such that there are no critical dimensions relative to one another. In addition to the elimination of the magnetic core section which encircles two other magnetic core sections, a construction commonly used in the prior art three-phase wound core configuration, the magnetic core structure taught by the invention requires only 75% of the core material of said prior art wound core structures. Although the invention does require one more winding section than three-phase transformers of the prior art, since two of the winding sections are smaller than the conventional winding sections, the extra weight and material required by the additional winding section is more than offset by the advantages realized by the teachings of the invention. For example, in addition to the savings in core weight, and elimination of certain manufacturing problems due to the absence of interrelated dimensions of the core sections and the relatively simple structures of the core sections, the transformer shown in FIGS. 1 and 2 has the advantages of placing positive pressure on the core joints by the individual banding means associated with each of the magnetic core sections, and the three phase magnetic circuit shown in FIGS. 1 and 2 is substantially balanced, as the reluctance from any one winding leg through the remaining legs is substantially the same for all winding legs.

A 3 kva. three-phase transformer was constructed according to the teachings of the invention, and the weight of the core and copper, as well as the core losses of the transformer, are listed in Table I as transformer type A. For comparision purposes, similar data for similarly rated prior art three-phase transformers having wound-type cores is listed under transformer types B and C in Table I. Transformer type B is of the type hereinbefore described, in which two similar wound sections are enclosed within a larger wound section. Transformer type C is a three-phase arrangement constructed of three single phase transformers. The weight savings realized by the teachings of the invention results in a cost savings of about the same ratio.

TABLE I

Transformer Type	A	B	C
Core Weight (lbs.)	20.5	26.8	34.2
Copper Weight (lbs.)	10.4	7.5	9.9
Total Active Weight	30.9	34.3	44.1
No Load Core Loss (watts)	21.5	26.4	30.0
Exciting Volt Amperes	134	110	150

The overall length of transformer **10** may be reduced by the width of two of the leg portions of the magnetic core sections, by offsetting or overlapping the magnetic core sections as shown in FIGS. 3 and 4. Like reference numerals in FIGS. 1, 2, 3 and 4 indicate like components.

More specifically, instead of aligning the magnetic core sections **20**, **22** and **24** into a single plane, in which the outer turn laminations of the legs are disposed adjacent one another, magnetic core sections **20** and **24** may be disposed such that their leg portions **32** and **46** overlap the leg portions **38** and **40** of magnetic core section **22**. In other words, the edges of the lamination turns of the core sections of the adjacent leg portions substantially abut one another to form winding legs **60** and **62**. In this instance, it may be desirable to form the magnetic core sections **20**, **22** and **24** of doubly oriented magnetic strip material, having a first direction of preferred magnetic grain orientation parallel with the edges of the magnetic strip, and a second direction of preferred magnetic grain orientation perpendicular to the edges of the magnetic strip, in order to reduce core losses.

Winding sections **64** and **70**, disposed about the end winding legs **38** and **48**, will be the same as in the embodiment of the invention shown in FIGS. 1 and 2. Winding sections **66'** and **68'**, however, are given prime marks to indicate that their window or opening dimensions may not be the same as in the embodiment shown in FIGS. 1 and 2. Although each embodiment would have the same cross sectional area of core material contained within the windings, the length and width dimensions of the opening may differ, depending upon the core build or stack height and width of the magnetic strip used in winding the core sections.

Magnetic core sections **20**, **22** and **24** are illustrated in FIGS. 3 with a stepped-lap type joint for opening the core sections, such as stepped lap joint **150** shown in magnetic core section **20**, to illustrate that other types of openable joints, other than the but-type joints shown in FIG. 1 may be used.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.

I claim as my invention:

1. A three-phase transformer comprising

first, second and third wound-type magnetic core sections, each having two leg portions, said first, second and third wound-type magnetic core sections being disposed adjacent one another to provide first, second, third and fourth winding legs, said second and third winding legs including leg portions of said first and second magnetic core sections, and said second and third magnetic core sections, respectively, and said first and fourth winding legs including the remaining leg portions of said first and third magnetic core sections, respectively,

first, second, third and fourth winding sections disposed in inductive relation with said first, second, third and fourth winding legs, respectively,

said second and third winding sections each forming a phase of the three-phase transformer,

said first and fourth winding sections being serially connected to form the third phase of the three-phase transformer.

2. The three-phase transformer of claim **1** wherein said first, second and third wound-type magnetic core sections each have substantially the same dimensions.

3. The three-phase transformer of claim **1** wherein said first and fourth winding sections have substantially the same dimensions, and said second and third winding sections have substantially the same dimensions, which are different from the dimensions of said first and fourth winding sections.

4. The three-phase transformer of claim **1** wherein each of said first, second, third and fourth winding sections have substantially the same number of conductor turns.

5. The three-phase transformer of claim **1** wherein each of said first, second, third and fourth winding sections have primary and secondary coils, with the primary coils having substantially the same number of conductor turns, and the secondary coils having substantially the same number of conductor turns, and with the primary coils and the secondary coils of said first and fourth winding sections being serially connected, respectively.

6. The three-phase transformer of claim 1 wherein the outer lamination turns of the winding legs of said first, second and third wound-type magnetic core sections are disposed in adjacent, substantially contacting relation to form said second and third winding legs.

7. The three-phase transformer of claim 1 wherein the edges of the lamination turns of the winding legs of said first, second and third wound-type magnetic core sections are disposed in adjacent relation to form said second and third winding legs.

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